EDA2 Imager PART A: Calculation of UVW

To begin with, I have hard-code the values of operating frequency.
(Next version would be to automate this process)

Telescope details:

- EDA2 data: 20200209, 256 Tiles

Duration of the project:

- Start Date : 26/08/2022
- End Date : 25/10/2022

Other notes:

- Auto-correlated visibilities, have not been included.

Importing libraries

In [1]:
```
# Importing fits library for viewing the images
from astropy.io import fits

# For plotting
import matplotlib.pyplot as plt

# For plotting 3D plots
from mpl_toolkits.mplot3d import Axes3D

# Using Pandas
import pandas as pd

# In order to use numpy
import numpy as np

# For performing math calculations
import math
from math import sin as sin
from math import cos as cos
from math import pi as pi
from math import sqrt as sqrt

# To check the system details
import sys

# To check the version of astropy
import astropy.version

import time

print('Versions Running on:')
print(f'\tPython\t\t{sys.version[:31]})')
print(f'\tAstropy\t\t{astropy.__version__}')
print(f'\tMatplotlib\t{plt.matplotlib.__version__}')
```

```
Versions Running on:
        Python          3.7.3 (default, Apr 24 2019, 15)
        Astropy         3.2.1
        Matplotlib      3.1.0
```

In [2]:
```
# Defining start time
start = time.process_time()
```

Assuming the frequency: 159.3750 MHz

In [3]:
```
# Defining and calculating all the constants

# speed of light : 3 x 10^8 m/s
c = 299792458.0
print('Speed of light(m/s):', c)

# operating frequency = 159.3750 MHz
frequency = 159.3750*(10**6)
print('Operating frequency in (Hz):', frequency)

# Calculating wavelength
wavelength = c/frequency
print('Calculated wavelength in (m):', wavelength)
```

```
Speed of light(m/s): 299792458.0
Operating frequency in (MHz): 159375000.0
Calculated wavelength in (m): 1.881050716862745
```

EDA2 Data

Step 1 : Getting the input visibilities: as real and imaginary data!

Inputs:

- **chan_204_20200209T034646_vis_real.fits**
- **chan_204_20200209T034646_vis_imag.fits**

In [4]:
```
vis_real = fits.open("chan_204_20200209T034646_vis_real.fits")
vis_imag = fits.open("chan_204_20200209T034646_vis_imag.fits")
```

In [5]:
```
vis_real_image = vis_real[0].data
vis_imag_image = vis_imag[0].data
```

In [6]:
```
# Examining the header for the real value of visibilities
vis_real[0].header
```

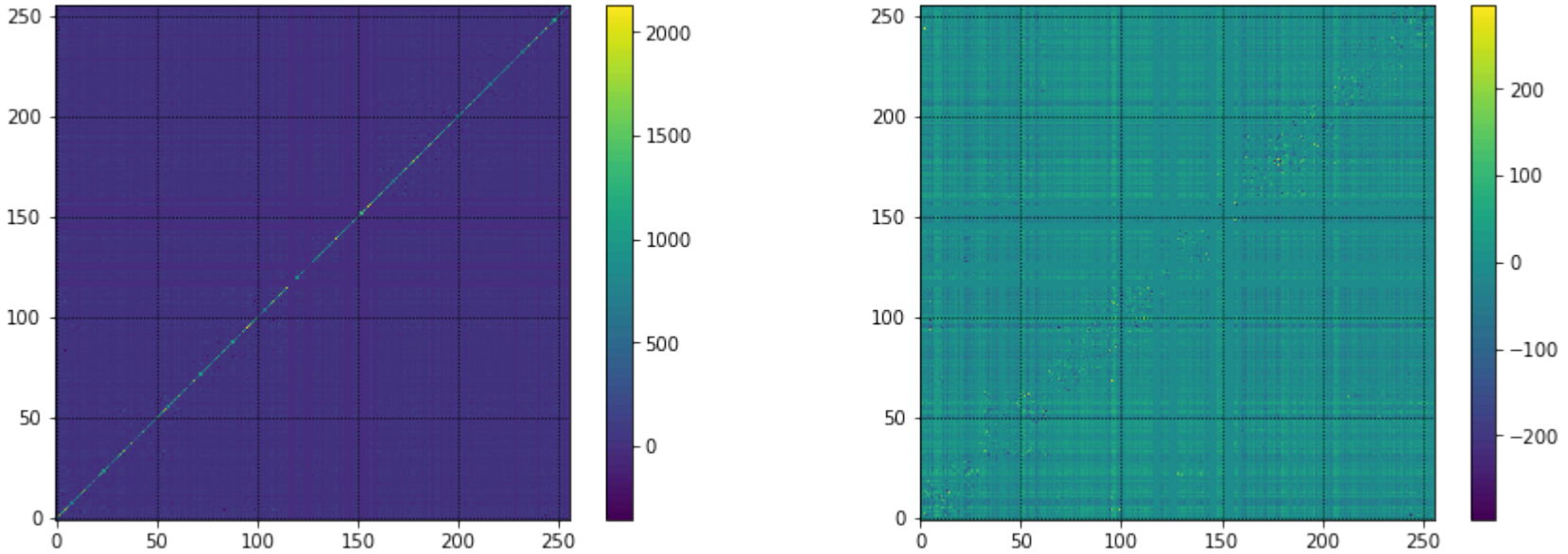
Out[6]:
```
SIMPLE  =                    T / conforms to FITS standard
BITPIX  =                  -64 / array data type
NAXIS   =                    2 / number of array dimensions
NAXIS1  =                  256
NAXIS2  =                  256
EXTEND  =                    T
```

In [7]:
```
# Examining the header for the imaginary value of visibilities
vis_imag[0].header
```

Out[7]:
```
SIMPLE  =                    T / conforms to FITS standard
BITPIX  =                  -64 / array data type
NAXIS   =                    2 / number of array dimensions
NAXIS1  =                  256
NAXIS2  =                  256
EXTEND  =                    T
```

In [8]:
```
# create figure
# fig = plt.figure(figsize=(15, 15))
fig = plt.figure(figsize=(15, 5))

# setting values to rows and column variables
rows = 1
columns = 2

# Adds a subplot
fig.add_subplot(rows, columns, 1)
plt.imshow(vis_real_image, origin="lower",aspect='equal')
plt.grid(color='black', ls='dotted')
plt.colorbar()

# Adds a subplot
fig.add_subplot(rows, columns, 2)
plt.imshow(vis_imag_image,origin="lower",aspect='equal')
plt.grid(color='black', ls='dotted')
plt.colorbar()
```

Out[8]:
```
<matplotlib.colorbar.Colorbar at 0x232f95ef128>
```



In [9]:
```
# Creating a dataframe for all the real and imaginary visibilities
df_vis_real = pd.DataFrame(vis_real_image)
df_vis_imag = pd.DataFrame(vis_imag_image)
```

In [10]:
```
df_vis_real
```

Out[10]:

	0	1	2	3	4	5	6	7	8	9	...	246	247	
0	328.867615	24.588898	21.415720	25.159893	23.272156	32.623756	67.544327	25.600283	-5.008373	56.130409	...	20.584955	23.733694	25.8
1	24.588898	1001.324097	32.625900	30.562368	42.107533	67.392723	49.459095	42.223946	30.334806	45.333996	...	21.941923	34.037449	69.6
2	21.415720	32.625900	1802.112183	-221.844772	5.765813	75.233185	28.925854	83.027077	53.337502	41.076969	...	-11.819213	103.449448	56.2
3	25.159893	30.562368	-221.844772	1310.901611	119.502617	68.835815	46.054825	41.802647	53.148262	54.665218	...	96.976486	-2.359920	38.5
4	23.272156	42.107533	5.765813	119.502617	1286.565674	65.288414	111.641373	72.028549	-37.939823	20.661905	...	54.904049	21.105185	40.4
...	...	...	...	...	...	...	...	...	...	...	...	...	...	
251	17.629080	64.068863	71.161095	48.846432	51.915932	60.429646	46.813198	33.485138	13.373882	42.458595	...	-13.461903	52.166763	74.2
252	12.726423	42.769550	-25.184362	41.607552	58.621078	44.896183	37.506577	30.086102	-22.894238	10.552099	...	29.180481	-74.083374	10.6
253	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	...	0.000000	0.000000	0.0
254	32.011589	63.610893	100.275230	20.950336	31.471109	71.682938	71.904350	36.675194	29.030394	56.140846	...	52.424744	151.915543	12.1
255	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	...	0.000000	0.000000	0.0

256 rows × 256 columns

In [11]:
```
df_vis_imag
```

Out[11]:

	0	1	2	3	4	5	6	7	8	9	...	246	247	248
0	0.000000	20.347363	5.232766	17.098120	13.575706	40.088928	-4.494764	36.376900	4.382819	-5.101678	...	8.985415	0.704096	5.380109
1	-20.347363	0.000000	-49.239357	23.557892	-10.475840	-7.355006	-58.698902	19.284822	27.034655	8.961044	...	-23.801003	-31.874340	-15.966197
2	-5.232766	49.239357	0.000000	-158.680908	-65.660355	7.385582	-44.348717	24.389639	97.863960	54.119991	...	-25.575441	73.233078	62.957054
3	-17.098120	-23.557892	158.680908	0.000000	-37.410690	-3.263887	-64.458542	-7.080525	10.403498	25.782703	...	-18.212944	-3.222548	-53.895336
4	-13.575706	10.475840	65.660355	37.410690	0.000000	42.297253	-14.743159	37.618340	86.671875	59.724304	...	5.650125	19.793768	14.020086
...	...	...	...	...	...	...	...	...	...	...	...	...	...	..
251	-13.179231	21.248463	19.817877	-29.501335	-35.181412	7.335309	-46.296852	14.544776	27.321148	30.595789	...	-90.726624	-7.259159	44.580070
252	-5.354980	23.853127	15.419326	70.752960	10.839559	27.200115	-15.889991	43.369865	53.596153	17.110559	...	13.591352	-54.479179	8.241980
253	-0.000000	-0.000000	-0.000000	-0.000000	-0.000000	-0.000000	-0.000000	-0.000000	-0.000000	-0.000000	...	-0.000000	-0.000000	-0.000000
254	-17.303267	34.438774	-60.391262	9.924271	-24.132935	15.218106	-56.081131	13.845360	25.737886	26.019999	...	-51.124516	-92.209778	-39.171150
255	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	...	0.000000	0.000000	0.000000

256 rows × 256 columns

Notes:

- We have visibilities corresponding to every antenna pair i.e every baseline
- Hence, number of visibilities = Na(Na-1)/2
- Here, for EDA2 configuration, Na = 256

Step 2 : Calculating u, v and w values from antenna positions.

Inputs: antenna_locations.txt

In [12]:
```
with open('antenna_locations.txt') as f:
    lines = f.readlines()
```

In [13]:
```
for item in lines:
    print(item)
```

```
# EDA2 antenna locations.

# lines beginning with '#' and blank lines are ignored. Do not leave spaces in empty lines.

# locations of antennas relative to the centre of the array in local topocentric

# "east". "north". "height". Units are meters.

# Format: Antenna_name east north height

# antenna names must be 8 chars or less

# fields are separated by white space

Ant061  6.437   4.975   -0.026

Ant063  -0.29   -0.256  0.016

Ant064  6.804   1.32    -0.001
```

We clearly need to do lots of data-cleaning to be able to read the antenna_positions.txt in a suitable format!

In [14]:
```
lines.pop(0)
```

Out[14]:
```
'# EDA2 antenna locations.\n'
```

In [15]:
```
lines.pop(0)
```

Out[15]:
```
"# lines beginning with '#' and blank lines are ignored. Do not leave spaces in empty lines.\n"
```

In [16]:
```
lines.pop(0)
```

Out[16]:
```
'# locations of antennas relative to the centre of the array in local topocentric\n'
```

In [17]:
```
lines.pop(0)
```

Out[17]:
```
'# "east". "north". "height". Units are meters.\n'
```

In [18]:
```
lines.pop(0)
```

Out[18]:
```
'# Format: Antenna_name east north height\n'
```

In [19]:
```
lines.pop(0)
```

Out[19]:
```
'# antenna names must be 8 chars or less\n'
```

In [20]:
```
lines.pop(0)
```

Out[20]:
```
'# fields are separated by white space\n'
```

In [21]:
```
lines
```

Out[21]:
```
['Ant061\t6.437\t4.975\t-0.026\n',
 'Ant063\t-0.29\t-0.256\t0.016\n',
 'Ant064\t6.804\t1.32\t-0.001\n',
 'Ant083\t5.331\t1.075\t-0.013\n',
 'Ant136\t-0.363\t3.256\t-0.010\n',
 'Ant124\t1.86\t9.002\t-0.037\n',
 'Ant123\t0.923\t6.104\t-0.031\n',
 'Ant122\t1.772\t4.249\t-0.012\n',
 'Ant084\t4.3\t3.282\t-0.029\n',
 'Ant085\t4.264\t5.952\t-0.048\n',
 'Ant086\t5.668\t6.391\t-0.029\n',
 'Ant097\t2.832\t6.377\t-0.036\n',
 'Ant121\t1.122\t2.964\t-0.006\n',
 'Ant120\t0.465\t1.694\t-0.010\n',
 'Ant099\t2.546\t1.643\t-0.001\n',
 'Ant098\t3.669\t4.665\t-0.034\n',
 'Ant134\t-0.521\t8.213\t-0.031\n',
 'Ant135\t-1.115\t6.463\t-0.028\n',
 'Ant152\t-2.806\t0.997\t0.015\n',
```

In [22]:
```
antenna_num_list = list()
x_positions_list = list()
y_positions_list = list()
z_positions_list = list()
```

In [23]:
```
antenna_positions = pd.DataFrame(columns=['Antenna_Name', 'X', 'Y', 'Z'])
```

In [24]:
```
# Ref : https://stackoverflow.com/questions/66698339/iterate-a-list-of-rows-and-split
result_list = []
for i in lines:
    k = i.split()
    result_list.append(k)
print(result_list[:5])
```

```
[['Ant061', '6.437', '4.975', '-0.026'], ['Ant063', '-0.29', '-0.256', '0.016'], ['Ant064', '6.804', '1.32', '-0.001'], ['Ant083', '5.331', '1.075', '-0.013'], ['Ant136', '-0.363', '3.256', '-0.010']]
```

In [25]:
```
# Ref : https://stackoverflow.com/questions/13188476/get-the-nth-element-from-the-inner-list-of-a-list-of-lists-in-python
antenna_name_list = [el[0] for el in result_list]
x_positions_list = [el[1] for el in result_list]
y_positions_list = [el[2] for el in result_list]
z_positions_list = [el[3] for el in result_list]
```

In [26]:
```
# Assigning the relevant lists as columns
antenna_positions['Antenna_Name'] = antenna_name_list
antenna_positions['X'] = x_positions_list
antenna_positions['Y'] = y_positions_list
antenna_positions['Z'] = z_positions_list
```

In [27]:
```
antenna_positions.head()
```

Out[27]:

	Antenna_Name	X	Y	Z
0	Ant061	6.437	4.975	-0.026
1	Ant063	-0.29	-0.256	0.016
2	Ant064	6.804	1.32	-0.001
3	Ant083	5.331	1.075	-0.013
4	Ant136	-0.363	3.256	-0.010

Understanding the data-frame:

Antenna_Number : Total number of antennas: 256

X : Towards East in meters.

Y : Towards North

Z : How high up the tile is from ground?

In [28]:
```
antenna_positions.describe()
```

Out[28]:

	Antenna_Name	X	Y	Z
count	256	256	256	256
unique	256	256	255	142
top	Ant050	-2.284	13.196	0.065
freq	1	1	2	5

In [29]:
```
antenna_positions.info()
```

```
<class 'pandas.core.frame.DataFrame'>
RangeIndex: 256 entries, 0 to 255
Data columns (total 4 columns):
 #   Column        Non-Null Count  Dtype 
---  ------        --------------  ----- 
 0   Antenna_Name  256 non-null    object
 1   X             256 non-null    object
 2   Y             256 non-null    object
 3   Z             256 non-null    object
dtypes: object(4)
memory usage: 8.1+ KB
```

In [30]:
```
antenna_positions['X'] = pd.to_numeric(antenna_positions['X'])
antenna_positions['Y'] = pd.to_numeric(antenna_positions['Y'])
antenna_positions['Z'] = pd.to_numeric(antenna_positions['Z'])
```

In [31]:
```
# Calculating X_lambda and creating a new column
antenna_positions['X_wavelength'] = antenna_positions['X']/wavelength

# Calculating Y_lambda and creating a new column
antenna_positions['Y_wavelength'] = antenna_positions['Y']/wavelength

# Assigning the Z_lambda value to be 0, as we are ignoring the height of the antenna?
antenna_positions['Z_wavelength'] = antenna_positions['Z']/wavelength

antenna_positions.head()
```

Out[31]:

	Antenna_Name	X	Y	Z	X_wavelength	Y_wavelength	Z_wavelength
0	Ant061	6.437	4.975	-0.026	3.422024	2.644798	-0.013822
1	Ant063	-0.290	-0.256	0.016	-0.154169	-0.136094	0.008506
2	Ant064	6.804	1.320	-0.001	3.617127	0.701735	-0.000532
3	Ant083	5.331	1.075	-0.013	2.834054	0.571489	-0.006911
4	Ant136	-0.363	3.256	-0.010	-0.192977	1.730947	-0.005316

In [32]:
```
antenna_positions.shape
```

Out[32]: (256, 7)

In [33]:
```
## Need to convert these Antenna_Number into a single digit from Ant061 to 61
```

In [34]:
```
a=np.array(antenna_positions['Antenna_Name'])
```

In [35]:
```
a[0][3:]
```

Out[35]: '061'

In [36]:
```
a1_list = list()
for i in range(len(antenna_positions['Antenna_Name'])):
    a1_list.append(int(a[i][3:]))
```

In [37]:
```
# antenna number only list
a1_list
```

Out[37]:
```
[61,
 63,
 64,
 83,
 136,
 124,
 123,
 122,
 84,
 85,
 86,
 97,
 121,
 120,
 99,
 98,
 134,
 135,
 152,
```

In [38]:
```
# Assigning the relevant lists as columns
# antenna_positions['Antenna_Number'] = a1_list
```

In [39]:
```
# antenna_positions.head()
```

In [40]:
```
a1_list.sort()
```

In [41]:
```
a1_list
```

Out[41]:
```
[1,
 2,
 3,
 4,
 5,
 6,
 7,
 8,
 9,
 10,
 11,
 12,
 13,
 14,
 15,
 16,
 17,
 18,
 19,
```

In [42]:
```
a1_list.append(0)
```

In [43]:
```
a1_list.sort()
```

In [44]:
```
a1_list.pop()
```

Out[44]:
```
256
```

In [45]:
```
a1_list
```

Out[45]:
```
[0,
 1,
 2,
 3,
 4,
 5,
 6,
 7,
 8,
 9,
 10,
 11,
 12,
 13,
 14,
 15,
 16,
 17,
 18,
```

In [46]:
```
# Assigning the relevant lists as columns
antenna_positions['Antenna_Number'] = a1_list
```

In [47]:
```
antenna_positions
```

Out[47]:

	Antenna_Name	X	Y	Z	X_wavelength	Y_wavelength	Z_wavelength	Antenna_Number
0	Ant061	6.437	4.975	-0.026	3.422024	2.644798	-0.013822	0
1	Ant063	-0.290	-0.256	0.016	-0.154169	-0.136094	0.008506	1
2	Ant064	6.804	1.320	-0.001	3.617127	0.701735	-0.000532	2
3	Ant083	5.331	1.075	-0.013	2.834054	0.571489	-0.006911	3
4	Ant136	-0.363	3.256	-0.010	-0.192977	1.730947	-0.005316	4
...	...	...	...	...	...	...	...	...
251	Ant018	12.660	-1.845	0.013	6.730281	-0.980835	0.006911	251
252	Ant033	10.136	1.940	-0.005	5.388478	1.031338	-0.002658	252
253	Ant022	13.759	3.242	-0.029	7.314529	1.723505	-0.015417	253
254	Ant020	13.901	0.835	0.001	7.390019	0.443901	0.000532	254
255	Ant019	12.608	0.097	0.017	6.702637	0.051567	0.009038	255

256 rows × 8 columns

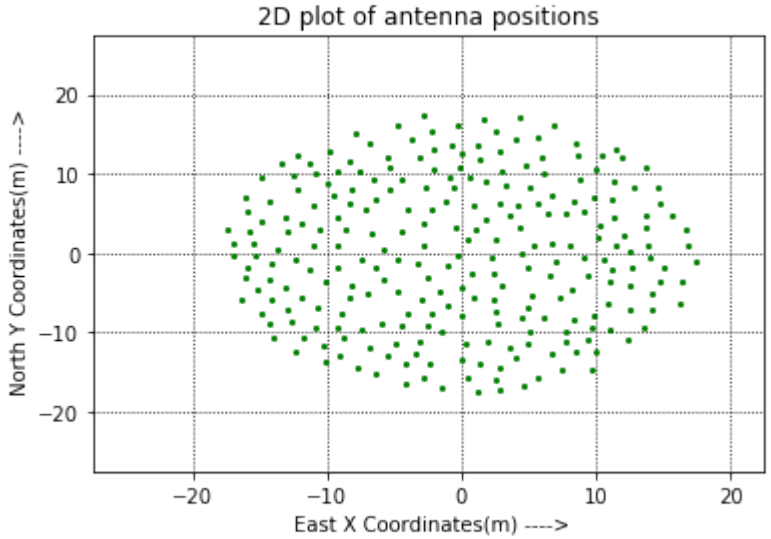
Visualising the antenna positions in 2D and 3D plots

In [48]:
```
# In order to plot all the X and Y coordinates as a dot on the grid, for better visualisation?

# First need to store all the X,Y and Z values as two lists?
Antenna_name_list = antenna_positions["Antenna_Name"].values.tolist()
Antenna_number_list = antenna_positions["Antenna_Number"].values.tolist()
X_list = antenna_positions["X"].values.tolist()
Y_list = antenna_positions["Y"].values.tolist()
Z_list = antenna_positions["Z"].values.tolist()
```

In [49]:
```
# Limits of x, y and z axis as the (min,max) values of X, Y and Z
print(min(X_list),",",max(X_list))
print(min(Y_list),",",max(Y_list))
print(round(min(Z_list),4),",",round(max(Z_list),4))
```

```
-17.345 , 17.517
-17.549 , 17.405
-0.089 , 0.116
```

In [50]:
```
# Plotting a 2D plot with X and Y values
# Ref link : # Ref link : https://www.tutorialspoint.com/how-can-i-plot-a-single-point-in-matplotlib-python

plt.xlim(min(X_list)-10, max(X_list)+5)
plt.ylim(min(Y_list)-10, max(Y_list)+10)
plt.rcParams["figure.autolayout"] = True
plt.grid(ls="dotted",color="black")
plt.xlabel(" East X Coordinates(m) ---->")
plt.ylabel(" North Y Coordinates(m) ---->")
plt.title("2D plot of antenna positions")

# Then iterate through the two lists and plot for x[i] and y[i]
for (x,y) in zip(X_list, Y_list):
    plt.plot(x, y, marker=".", markersize=4, markeredgecolor="green", markerfacecolor="green")
```



In [51]:
```
# Defining a new dataframe to store the visibilities values
df_uvw = pd.DataFrame(columns=['Antenna_1','Antenna_2'])

# Viewing the dataframe for u,v w coordinates
df_uvw.head()
```

Out[51]:

	Antenna_1	Antenna_2

In [52]:
```
Antenna_number_list
```

Out[52]:
```
[0,
 1,
 2,
 3,
 4,
 5,
 6,
 7,
 8,
 9,
 10,
 11,
 12,
 13,
 14,
 15,
 16,
 17,
 18,
```

Populating the dataframe with antenna 1 and antenna 2 values

- row 1 : 0 0
- row 2 : 0 1
- row 3 : 0 2
- row 4 : 0 3

Total expected pairs (baselines) i.e rows : (256 x 255) / 2 = **32640**

In [53]:
```
min(Antenna_number_list)
```

Out[53]:
```
0
```

In [54]:
```
max(Antenna_number_list)
```

Out[54]:
```
255
```

Note: There is no need to sort the antenna_number_list, the list/.txt file are already sorted. So, will need to use them as it is, to populate the new dataframe!

In [55]:
```
# Ref : https://www.codegrepper.com/code-examples/python/append+row+to+dataframe
for i in Antenna_number_list:
    for j in Antenna_number_list:
        if(i!=j):
            df_uvw = df_uvw.append({'Antenna_1':i, 'Antenna_2':j}, ignore_index=True)

# View the populated df
df_uvw
```

Out[55]:

	Antenna_1	Antenna_2
0	0	1
1	0	2
2	0	3
3	0	4
4	0	5
...	...	...
65275	255	250
65276	255	251
65277	255	252
65278	255	253
65279	255	254

65280 rows × 2 columns

In [56]:
```
# Function for X_lamba value for a given pair of antennas
# Ref : https://stackoverflow.com/questions/36684013/extract-column-value-based-on-another-column-pandas-dataframe
# df.loc[df['B'] == 3, 'A']
def calculate_X_lambda(row):
    # Initialise the value of X_lambda to be 0
    X_lambda = 0

    # Get the relevant value of X Coordinate, i.e X1 for Antenna 1
    A1 = row["Antenna_1"]
    X1 = antenna_positions.loc[antenna_positions['Antenna_Number'] == A1, 'X_wavelength']
    value1 = float(X1)

    # Get the relevant value of X Coordinate, i.e X2 for Antenna 2
    A2 = row["Antenna_2"]
    X2 = antenna_positions.loc[antenna_positions['Antenna_Number'] == A2, 'X_wavelength']
    value2 = float(X2)

    # Calculate the value of X_lambda
    X_lambda = float(value1 - value2)

    # Return the value of calculated lambda
    return X_lambda
```

In [57]:
```
# Assigning calculated X_lambda values
df_uvw['X_lambda'] = df_uvw.apply(lambda x : calculate_X_lambda(x), axis = 1)
df_uvw.head()
```

Out[57]:

	Antenna_1	Antenna_2	X_lambda
0	0	1	3.576193
1	0	2	-0.195104
2	0	3	0.587969
3	0	4	3.615001
4	0	5	2.433215

In [58]:
```
# Function for Y_lamba value for a given pair of antennas
def calculate_Y_lambda(row):
    # Initialise the value of X_lambda to be 0
    Y_lambda = 0

    # Get the relevant value of X Coordinate, i.e X1 for Antenna 1
    A1 = row["Antenna_1"]
    Y1 = antenna_positions.loc[antenna_positions['Antenna_Number'] == A1, 'Y_wavelength']
    value1 = float(Y1)

    # Get the relevant value of X Coordinate, i.e X2 for Antenna 2
    A2 = row["Antenna_2"]
    Y2 = antenna_positions.loc[antenna_positions['Antenna_Number'] == A2, 'Y_wavelength']
    value2 = float(Y2)

    # Calculate the value of X_lambda
    Y_lambda = float(value1 - value2)

    # Return the value of calculated lambda
    return Y_lambda
```

In [59]:
```
# Assigning calculated Y_lambda values
df_uvw['Y_lambda'] = df_uvw.apply(lambda x : calculate_Y_lambda(x), axis = 1)
df_uvw.head()
```

Out[59]:

	Antenna_1	Antenna_2	X_lambda	Y_lambda
0	0	1	3.576193	2.780893
1	0	2	-0.195104	1.943063
2	0	3	0.587969	2.073309
3	0	4	3.615001	0.913851
4	0	5	2.433215	-2.140825

In [60]:
```
# Function for Z_lamba value for a given pair of antennas
def calculate_Z_lambda(row):
    # Initialise the value of Z_lambda to be 0
    Z_lambda = 0

    # Get the relevant value of X Coordinate, i.e X1 for Antenna 1
    A1 = row["Antenna_1"]
    Z1 = antenna_positions.loc[antenna_positions['Antenna_Number'] == A1, 'Z_wavelength']
    value1 = float(Z1)

    # Get the relevant value of X Coordinate, i.e X2 for Antenna 2
    A2 = row["Antenna_2"]
    Z2 = antenna_positions.loc[antenna_positions['Antenna_Number'] == A2, 'Z_wavelength']
    value2 = float(Z2)

    # Calculate the value of Z_lambda
    Z_lambda = float(value1 - value2)

    # Return the value of calculated lambda
    return Z_lambda
```

In [61]:
```
# Assigning calculated Z_lambda values
df_uvw['Z_lambda'] = df_uvw.apply(lambda x : calculate_Z_lambda(x), axis = 1)
df_uvw.head()
```

Out[61]:

	Antenna_1	Antenna_2	X_lambda	Y_lambda	Z_lambda
0	0	1	3.576193	2.780893	-0.022328
1	0	2	-0.195104	1.943063	-0.013290
2	0	3	0.587969	2.073309	-0.006911
3	0	4	3.615001	0.913851	-0.008506
4	0	5	2.433215	-2.140825	0.005848

In [62]:
```
df_uvw.shape
```

Out[62]:
```
(65280, 5)
```

Calculating u, v and w coordinates from X_lambda, Y_lambda and Z_lambda values:

In [63]:
```
# Reference:
# Pg 110 Chapter 4.1 Thompson, Moran and Swenson(TMS)
# u = sin(H)*(X_lambda) + cos(H)*(Y_lambda)
# v = -sin(delta)*cos(H)*(X_lambda) + sin(delta)*sin(H)*(Y_lambda) + cos(delta)*(Z_lambda)
# w = cos(delta)*cos(H)*(X_lambda) - cos(delta)*sin(H)*(Y_lambda) + sin(delta)*(Z_lambda)

# For EDA2 Data, u = Xlambda, v = Ylambda and w = Zlambda
# H = 90 Degrees?
# delta = 90 Degrees?
```

In [64]:
```
# Assign u, v and w values
df_uvw['u'] = df_uvw['X_lambda']
df_uvw['v'] = df_uvw['Y_lambda']
df_uvw['w'] = df_uvw['Z_lambda']
df_uvw.head()
```

Out[64]:

	Antenna_1	Antenna_2	X_lambda	Y_lambda	Z_lambda	u	v	w
0	0	1	3.576193	2.780893	-0.022328	3.576193	2.780893	-0.022328
1	0	2	-0.195104	1.943063	-0.013290	-0.195104	1.943063	-0.013290
2	0	3	0.587969	2.073309	-0.006911	0.587969	2.073309	-0.006911
3	0	4	3.615001	0.913851	-0.008506	3.615001	0.913851	-0.008506
4	0	5	2.433215	-2.140825	0.005848	2.433215	-2.140825	0.005848

In [65]:
```
# Calculating u, v and w in meters

# Calculating u_m
df_uvw['u_m'] = df_uvw['u']*(wavelength)

# Calculating v_m
df_uvw['v_m'] = df_uvw['v']*(wavelength)

# Calculating w_m
df_uvw['z_m'] = df_uvw['w']*(wavelength)
```

Visualing these u, v and w coordinates corresponding to every pair!

In [66]:
```
df_uvw.shape
```

Out[66]:
```
(65280, 11)
```

In [67]:
```
df_uvw.info()
```

```
<class 'pandas.core.frame.DataFrame'>
RangeIndex: 65280 entries, 0 to 65279
Data columns (total 11 columns):
 #   Column     Non-Null Count  Dtype  
---  ------     --------------  -----  
 0   Antenna_1  65280 non-null  object 
 1   Antenna_2  65280 non-null  object 
 2   X_lambda   65280 non-null  float64
 3   Y_lambda   65280 non-null  float64
 4   Z_lambda   65280 non-null  float64
 5   u          65280 non-null  float64
 6   v          65280 non-null  float64
 7   w          65280 non-null  float64
 8   u_m        65280 non-null  float64
 9   v_m        65280 non-null  float64
 10  z_m        65280 non-null  float64
dtypes: float64(9), object(2)
memory usage: 5.5+ MB
```

In [68]:
```
df_uvw.describe()
```

Out[68]:

	X_lambda	Y_lambda	Z_lambda	u	v	w	u_m	v_m	z_m
count	6.528000e+04	6.528000e+04	6.528000e+04	6.528000e+04	6.528000e+04	6.528000e+04	6.528000e+04	6.528000e+04	6.528000e+04
mean	5.924890e-15	-7.096210e-17	3.352922e-18	5.924890e-15	-7.096210e-17	3.352922e-18	-2.423320e-15	1.798835e-14	-1.105546e-17
std	6.814688e+00	6.757373e+00	3.691752e-02	6.814688e+00	6.757373e+00	3.691752e-02	1.281877e+01	1.271096e+01	6.944372e-02
min	-1.853326e+01	-1.858217e+01	-1.089816e-01	-1.853326e+01	-1.858217e+01	-1.089816e-01	-3.486200e+01	-3.495400e+01	-2.050000e-01
25%	-4.883441e+00	-4.829748e+00	-2.658089e-02	-4.883441e+00	-4.829748e+00	-2.658089e-02	-9.186000e+00	-9.085000e+00	-5.000000e-02
50%	0.000000e+00	0.000000e+00	0.000000e+00	0.000000e+00	0.000000e+00	0.000000e+00	0.000000e+00	0.000000e+00	0.000000e+00
75%	4.883441e+00	4.829748e+00	2.658089e-02	4.883441e+00	4.829748e+00	2.658089e-02	9.186000e+00	9.085000e+00	5.000000e-02
max	1.853326e+01	1.858217e+01	1.089816e-01	1.853326e+01	1.858217e+01	1.089816e-01	3.486200e+01	3.495400e+01	2.050000e-01

In [69]:
```
u_list = df_uvw["u"].values.tolist()
v_list = df_uvw["v"].values.tolist()
w_list = df_uvw["w"].values.tolist()
```

In [70]:
```
print(min(u_list), max(u_list))
print(min(v_list), max(v_list))
print(min(w_list), max(w_list))
```

```
-18.533258932084273 18.533258932084273
-18.582167767542707 18.582167767542707
-0.10898164422802124 0.10898164422802124
```

Getting a 2D View of the U,V Coordinates

In [71]:
```
# # Plotting a 2D plot with u and v values
# # Ref link : # Ref link : https://www.tutorialspoint.com/how-can-i-plot-a-single-point-in-matplotlib-python

# plt.xlim(min(u_list)-10, max(u_list)+5)
# plt.ylim(min(v_list)-10, max(v_list)+10)
# plt.rcParams["figure.autolayout"] = True
# plt.grid(ls="dotted",color="black")
# plt.xlabel(" East u Coordinates(m) ---->")
# plt.ylabel(" North v Coordinates(m) ---->")
# plt.title("2D plot of u,v coordinates")

# # Then iterate through the two lists and plot for x[i] and y[i]
# for (u,v) in zip(u_list, v_list):
#     plt.plot(u, v, marker=".", markersize=0.25, markeredgecolor="orange", markerfacecolor="orange")
```

Getting a 3D View of the U,V,W Coordinates

In [72]:
```
# # Plotting a 3D plot with U, V and W values

# fig = plt.figure(figsize=(10,5))
# ax = fig.add_subplot(111, projection='3d')
# ax.grid(ls="dotted", color="black")

# # Setting the limits
# ax.set_xlim(min(u_list)-10,max(u_list)+5)
# ax.set_ylim(min(v_list)-10, max(v_list)+10+10)
# ax.set_zlim(min(w_list),max(w_list))


# # Iterating through the three lists and plot for x[i] and y[i]
# for (u,v,w) in zip(u_list, v_list, w_list):
#     ax.scatter(u, v, w, marker = ".", c = "blue") # plot the point (u,v,w) on the figure

# ax.set_title("3D plot of (U,V,W):")
# ax.set_xlabel("u Coordinates ---->")
# ax.set_ylabel("v Coordinates ---->")
# ax.set_zlabel("w Coordinates ---->")
# # plt.show()
```

In [73]:
```
df_uvw
```

Out[73]:

	Antenna_1	Antenna_2	X_lambda	Y_lambda	Z_lambda	u	v	w	u_m	v_m	z_m
0	0	1	3.576193	2.780893	-0.022328	3.576193	2.780893	-0.022328	6.727	5.231	-0.042
1	0	2	-0.195104	1.943063	-0.013290	-0.195104	1.943063	-0.013290	-0.367	3.655	-0.025
2	0	3	0.587969	2.073309	-0.006911	0.587969	2.073309	-0.006911	1.106	3.900	-0.013
3	0	4	3.615001	0.913851	-0.008506	3.615001	0.913851	-0.008506	6.800	1.719	-0.016
4	0	5	2.433215	-2.140825	0.005848	2.433215	-2.140825	0.005848	4.577	-4.027	0.011
...	...	...	...	...	...	...	...	...	...	...	...
65275	255	250	-1.115334	1.952632	0.007443	-1.115334	1.952632	0.007443	-2.098	3.673	0.014
65276	255	251	-0.027644	1.032402	0.002126	-0.027644	1.032402	0.002126	-0.052	1.942	0.004
65277	255	252	1.314159	-0.979772	0.011696	1.314159	-0.979772	0.011696	2.472	-1.843	0.022
65278	255	253	-0.611892	-1.671938	0.024454	-0.611892	-1.671938	0.024454	-1.151	-3.145	0.046
65279	255	254	-0.687382	-0.392334	0.008506	-0.687382	-0.392334	0.008506	-1.293	-0.738	0.016

65280 rows × 11 columns

In [74]:
```
df_uvw.Antenna_1 = df_uvw.Antenna_1.astype(int)
df_uvw.Antenna_2 = df_uvw.Antenna_2.astype(int)
df_uvw.info()
```

```
<class 'pandas.core.frame.DataFrame'>
RangeIndex: 65280 entries, 0 to 65279
Data columns (total 11 columns):
 #   Column     Non-Null Count  Dtype  
---  ------     --------------  -----  
 0   Antenna_1  65280 non-null  int32  
 1   Antenna_2  65280 non-null  int32  
 2   X_lambda   65280 non-null  float64
 3   Y_lambda   65280 non-null  float64
 4   Z_lambda   65280 non-null  float64
 5   u          65280 non-null  float64
 6   v          65280 non-null  float64
 7   w          65280 non-null  float64
 8   u_m        65280 non-null  float64
 9   v_m        65280 non-null  float64
 10  z_m        65280 non-null  float64
dtypes: float64(9), int32(2)
memory usage: 5.0 MB
```

In [75]:
```
df_vis_imag.head()
```

Out[75]:

	0	1	2	3	4	5	6	7	8	9	...	246	247	248
0	0.000000	20.347363	5.232766	17.098120	13.575706	40.088928	-4.494764	36.376900	4.382819	-5.101678	...	8.985415	0.704096	5.380109
1	-20.347363	0.000000	-49.239357	23.557892	-10.475840	-7.355006	-58.698902	19.284822	27.034655	8.961044	...	-23.801003	-31.874340	-15.966197
2	-5.232766	49.239357	0.000000	-158.680908	-65.660355	7.385582	-44.348717	24.389639	97.863960	54.119991	...	-25.575441	73.233078	62.957054
3	-17.098120	-23.557892	158.680908	0.000000	-37.410690	-3.263887	-64.458542	-7.080525	10.403498	25.782703	...	-18.212944	-3.222548	-53.895336
4	-13.575706	10.475840	65.660355	37.410690	0.000000	42.297253	-14.743159	37.618340	86.671875	59.724304	...	5.650125	19.793768	14.020086

5 rows × 256 columns

In [76]:
```
# Checking for Nulls in Visibilities, imaginary
df_vis_imag.isna().sum()
```

Out[76]:
```
0      0
1      0
2      0
3      0
4      0
      ..
251    0
252    0
253    0
254    0
255    0
Length: 256, dtype: int64
```

In [77]:
```
# Checking for Nulls in Visibilities, real
df_vis_real.head()
```

Out[77]:

	0	1	2	3	4	5	6	7	8	9	...	246	247	
0	328.867615	24.588898	21.415720	25.159893	23.272156	32.623756	67.544327	25.600283	-5.008373	56.130409	...	20.584955	23.733694	25.835
1	24.588898	1001.324097	32.625900	30.562368	42.107533	67.392723	49.459095	42.223946	30.334806	45.333996	...	21.941923	34.037449	69.689
2	21.415720	32.625900	1802.112183	-221.844772	5.765813	75.233185	28.925854	83.027077	53.337502	41.076969	...	-11.819213	103.449448	56.257
3	25.159893	30.562368	-221.844772	1310.901611	119.502617	68.835815	46.054825	41.802647	53.148262	54.665218	...	96.976486	-2.359920	38.590
4	23.272156	42.107533	5.765813	119.502617	1286.565674	65.288414	111.641373	72.028549	-37.939823	20.661905	...	54.904049	21.105185	40.463

5 rows × 256 columns

In [78]:
```
df_vis_real.isna().sum()
```

Out[78]:
```
0      0
1      0
2      0
3      0
4      0
      ..
251    0
252    0
253    0
254    0
255    0
Length: 256, dtype: int64
```

In [79]:
```
df_uvw.head()
```

Out[79]:

	Antenna_1	Antenna_2	X_lambda	Y_lambda	Z_lambda	u	v	w	u_m	v_m	z_m
0	0	1	3.576193	2.780893	-0.022328	3.576193	2.780893	-0.022328	6.727	5.231	-0.042
1	0	2	-0.195104	1.943063	-0.013290	-0.195104	1.943063	-0.013290	-0.367	3.655	-0.025
2	0	3	0.587969	2.073309	-0.006911	0.587969	2.073309	-0.006911	1.106	3.900	-0.013
3	0	4	3.615001	0.913851	-0.008506	3.615001	0.913851	-0.008506	6.800	1.719	-0.016
4	0	5	2.433215	-2.140825	0.005848	2.433215	-2.140825	0.005848	4.577	-4.027	0.011

In [80]:
```
df_uvw.shape
```

Out[80]:
```
(65280, 11)
```

In [81]:
```
df_uvw.describe()
```

Out[81]:

	Antenna_1	Antenna_2	X_lambda	Y_lambda	Z_lambda	u	v	w	u_m	v_m	
count	65280.000000	65280.000000	6.528000e+04	6.528000e+04	6.528000e+04	6.528000e+04	6.528000e+04	6.528000e+04	6.528000e+04	6.528000e+04	6.52
mean	127.500000	127.500000	5.924890e-15	-7.096210e-17	3.352922e-18	5.924890e-15	-7.096210e-17	3.352922e-18	-2.423320e-15	1.798835e-14	-1
std	73.900837	73.900837	6.814688e+00	6.757373e+00	3.691752e-02	6.814688e+00	6.757373e+00	3.691752e-02	1.281877e+01	1.271096e+01	6.9
min	0.000000	0.000000	-1.853326e+01	-1.858217e+01	-1.089816e-01	-1.853326e+01	-1.858217e+01	-1.089816e-01	-3.486200e+01	-3.495400e+01	-2
25%	63.750000	63.750000	-4.883441e+00	-4.829748e+00	-2.658089e-02	-4.883441e+00	-4.829748e+00	-2.658089e-02	-9.186000e+00	-9.085000e+00	-5
50%	127.500000	127.500000	0.000000e+00	0.000000e+00	0.000000e+00	0.000000e+00	0.000000e+00	0.000000e+00	0.000000e+00	0.000000e+00	0.0(
75%	191.250000	191.250000	4.883441e+00	4.829748e+00	2.658089e-02	4.883441e+00	4.829748e+00	2.658089e-02	9.186000e+00	9.085000e+00	5.0
max	255.000000	255.000000	1.853326e+01	1.858217e+01	1.089816e-01	1.853326e+01	1.858217e+01	1.089816e-01	3.486200e+01	3.495400e+01	2.0

In [82]:
```
# Checking for NaNs
df_uvw.isna().sum()
```

Out[82]:
```
Antenna_1    0
Antenna_2    0
X_lambda     0
Y_lambda     0
Z_lambda     0
u            0
v            0
w            0
u_m          0
v_m          0
z_m          0
dtype: int64
```

In [83]:
```
type(Antenna_number_list[0])
```

Out[83]:
```
int
```

In [84]:
```
Antenna_number_list[0]
```

Out[84]:
```
0
```

Filling the visibilities, for the relevant antenna pairs (i.e baselines)

- Auto-correlated visibilities, have not been included.

In [85]:
```
# Ref link : https://stackoverflow.com/questions/71574873/assign-one-column-value-to-another-column-based-on-condition-in-pandas
for i in range(len(Antenna_number_list)):
    for j in range(len(Antenna_number_list)):
        real = df_vis_real.iat[i,j]
        imag = df_vis_imag.iat[i,j]

        # Set value to vis_real based on Antenna 1 and Antenna 2 values
        mask = (df_uvw['Antenna_1']==i) & (df_uvw['Antenna_2']==j)
        df_uvw.loc[mask, "vis_real"] = real

        # Set value to vis_imag based on Antenna 1 and Antenna 2 values
        df_uvw.loc[mask, "vis_imag"] = imag
```

In [86]:
```
df_uvw.head()
```

Out[86]:

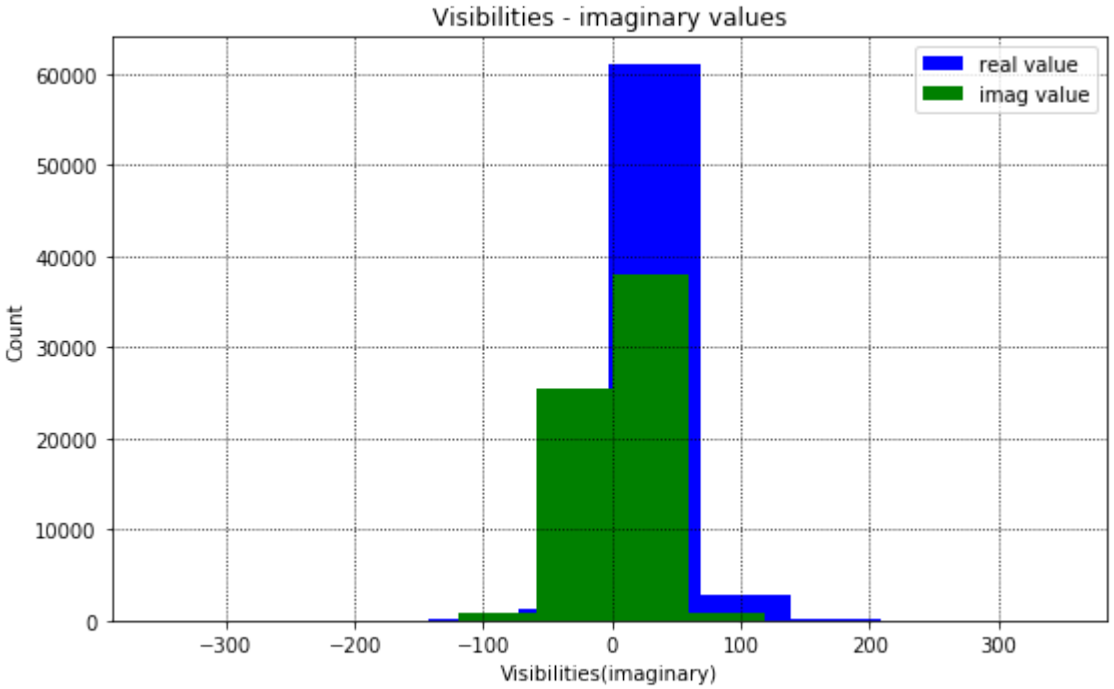
	Antenna_1	Antenna_2	X_lambda	Y_lambda	Z_lambda	u	v	w	u_m	v_m	z_m	vis_real	vis_imag
0	0	1	3.576193	2.780893	-0.022328	3.576193	2.780893	-0.022328	6.727	5.231	-0.042	24.588898	20.347363
1	0	2	-0.195104	1.943063	-0.013290	-0.195104	1.943063	-0.013290	-0.367	3.655	-0.025	21.415720	5.232766
2	0	3	0.587969	2.073309	-0.006911	0.587969	2.073309	-0.006911	1.106	3.900	-0.013	25.159893	17.098120
3	0	4	3.615001	0.913851	-0.008506	3.615001	0.913851	-0.008506	6.800	1.719	-0.016	23.272156	13.575706
4	0	5	2.433215	-2.140825	0.005848	2.433215	-2.140825	0.005848	4.577	-4.027	0.011	32.623756	40.088928

- The conjugate visibilities, have also been accounted for.
- Also, there are no NaN values of visibilities.

In [87]:
```
# Plotting an histogram of the real and imaginary values of visibilities

# create figure
# fig = plt.figure(figsize=(15, 15))
fig = plt.figure(figsize=(15, 5))

# setting values to rows and column variables
rows = 1
columns = 2

# Adds a subplot
fig.add_subplot(rows, columns, 1)
# Plotting histogram for real values of visibilities
plt.hist(df_uvw['vis_real'], color = 'blue', label="real value")
plt.title('Visibilities - real values')
plt.xlabel('Visibilities(real)')
plt.ylabel('Count')
plt.grid(ls="dotted", color="black")
plt.legend()

# Adds a subplot
fig.add_subplot(rows, columns, 1)
# Plotting histogram for imaginary values of visibilities
plt.hist(df_uvw['vis_imag'], color = 'green', label="imag value")
plt.title('Visibilities - imaginary values')
plt.xlabel('Visibilities(imaginary)')
plt.ylabel('Count')
plt.grid(ls="dotted", color="black")
plt.legend()
```

```
C:\Users\Gayatri Aniruddha\Anaconda3\lib\site-packages\ipykernel_launcher.py:22: MatplotlibDeprecationWarning: Adding an axes u
sing the same arguments as a previous axes currently reuses the earlier instance.  In a future version, a new instance will alw
ays be created and returned.  Meanwhile, this warning can be suppressed, and the future behavior ensured, by passing a unique l
abel to each axes instance.
```

Out[87]:
```
<matplotlib.legend.Legend at 0x232fadf9080>
```



In [88]:
```
# Really important excel to be saved
df_uvw.to_excel(r'C:\Users\Gayatri Aniruddha\Downloads\df_uvw_EDA2_20200209.xlsx', index = False)
```

In [89]:
```
# Overall time taken in seconds
print("Overall time in seconds:", time.process_time() - start)
```

```
Overall time in seconds: 322.40625
```

Notes:

- The final results of the resulting dataframe have been stored in this excel.